# MANUFACTURED HOUSING WALLS THAT PROVIDE SATISFACTORY MOISTURE PERFORMANCE IN ALL CLIMATES

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## ABSTRACT

We used the MOIST Computer Model to conduct a detailed analysis of the moisture performance of one wall typical of current construction practice in manufactured housing, and two new alternative wall designs with potential for better moisture performance in a wider variety of climates. The analysis showed that the current-practice wall with an interior vapor retarder performed acceptably in a cold climate (Madison, WI), but poorly in a hot and humid climate (Miami, FL). The alternative wall designs both exhibited satisfactory moisture performance in the cold climate and the hot and humid climate, even with moderately severe indoor conditions. The alternative wall designs also performed satisfactorily in a mixed climate (Little Rock, AR). These alternative wall designs should be of interest to the manufactured housing industry, who distributes houses to all climatic regions of the United States.

## INTRODUCTION

During cold weather, the absolute humidity of the air within a heated, occupied residence is considerably higher than that of the outdoor air. In this situation, moisture from the indoor environment permeates walls by way of diffusion and air exfiltration through openings and cracks in the construction. This moisture is partially adsorbed and accumulates at exterior layers of the construction. Duff (1968) observed that the moisture content in outer layers of the wall increases during cold winter periods and subsequently decreases during warm summer periods. If an interior vapor retarder and air barrier are not present in the construction, the moisture content of the sheathing and siding materials may approach and rise above fiber saturation. In this situation, these materials are susceptible to buckling and warping, paint peeling, pushed out nails, and fungal deterioration.

During the winter, more moisture may accumulate in the walls of manufactured housing than in those of site-built houses. This is because manufactured homes tend to have higher indoor water-vapor pressures compared to conventional houses due to their smaller volumes and their lower infiltration rates (Burch 1991). Water-vapor pressure is one of the driving forces that causes moisture transfer in building envelopes.

The Department of Housing and Urban Development's Manufactured Home Construction and Safety Standards (1993) contain rules to control moisture accumulation in the walls during winter. These rules are applied to all climatic regions of the United States and require manufactured homes to use one of the following practices: 1) install an interior vapor retarder with a permeance of 57 $ng/s{\cdot}m^2{\cdot}Pa$ (1 perm) or less, or 2) use permeable sheathing and siding that has a combined permeance higher than 290 $ng/s{\cdot}m^2{\cdot}Pa$ (5 perm), or 3) provide an outdoor ventilated cavity between the siding and wall insulation. For practices 2 and 3, the HUD Standards do not require an interior vapor retarder. TenWolde and Carll (1992) have previously shown that a ventilated wall (practice 3) may provide poor moisture performance in both a hot and humid climate and a cold climate and this practice is therefore not considered in this report.

These same three moisture-control practices are applied to manufactured homes sold in hot and humid climates and may lead to mold and mildew problems as discussed below. During the summer, outdoor moisture permeates into a building and is adsorbed (or condenses) at interior wall surfaces cooled by air conditioning. When the exterior

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construction is permeable to water vapor or outdoor air infiltrates into the construction, the relative humidity at the outside surface of an interior vapor retarder (e.g., vinyl wallpaper) can approach saturation and lead to mold and mildew growth. Fungal spores from mold and mildew subsequently can enter the living space and cause indoor air quality and health problems (e.g., musty odor, respiratory illness, and allergies).

The National Institute of Standards and Technology (NIST) has developed a computer model, called MOIST, that predicts the transfer of heat and moisture in a multi-layer wall under nonisothermal conditions (Burch and Thomas 1991). MOIST calculates the moisture content of the construction layers as a function of time. The model includes one-dimensional moisture transfer by diffusion and capillary flow. The moisture-transfer permeances offered by vapor retarders and paint layers are readily included in simulations. The model accounts for convective moisture transfer by including air cavities which may be coupled to indoor and outdoor air. MOIST has recently been verified by way of comparison to a series of experiments (Zarr, et al. 1995).

In the present report, MOIST is used first to investigate the moisture performance of a current-practice wall construction and subsequently to investigate the performance of two alternative walls which have the potential for satisfactory moisture performance in all climates of the United States. A one-dimensional model, such as MOIST, can of course only provide approximate average moisture performance for actual three-dimensional constructions. However, it is appropriate to use such models to compare the performance of alternative constructions, and use the results to assess the expected effectiveness of changes in design.

## DISCUSSION OF MODEL

### Theory

Within each layer of a wall construction, moisture transfer is governed by the following one-dimensional conservation of mass equation:

$$\frac{\partial}{\partial y}\left(D_\gamma(\gamma,T)\frac{\partial\gamma}{\partial y}\right) + \frac{\partial}{\partial y}\left(D_T(\gamma,T)\frac{\partial T}{\partial y}\right) = \frac{\partial\gamma}{\partial t} \qquad (1)$$

Symbols are defined in the Nomenclature. The selection of moisture content ($\gamma$) and temperature (T) as potentials has the advantage that the same mathematical formulation includes both diffusion transfer and capillary transfer. This formulation is equivalent to using the gradient in vapor pressure as the moisture transfer potential in the diffusion regime and suction pressure in the capillary flow regime, with a single required diffusivity function.

Heat transfer is governed by the one-dimensional conservation of energy equation:

$$\frac{\partial}{\partial y}\left(k(\gamma,T)\frac{\partial T}{\partial y}\right) = \rho_d\,(C_d + \gamma C_w)\frac{\partial T}{\partial t} \qquad (2)$$

Latent transport of heat is included at the boundaries of the layers (Burch and Thomas 1991). The other components of enthalpy transport by moisture movement within the layers are generally small and are therefore neglected in the analysis. The term ($C_d + \gamma C_w$) includes the effect of energy storage in both the dry material and accumulated moisture.

In the above two governing equations, strong couplings exist between heat and moisture transfer. Both the diffusivity for the moisture gradient ($D_\gamma$) and the diffusivity for the temperature gradient ($D_T$) are strong functions of moisture content and temperature. The thermal conductivity (k) can also be a function of moisture content and temperature, but for the present analysis it is assumed to be constant.

In the diffusion regime, the diffusivity for the moisture gradient ($D_\gamma$) and the diffusivity for the temperature gradient ($D_T$) were calculated in terms of measured permeability by the relations:

$$D_\gamma = \frac{\mu(\phi)\,P_{sat}(T)}{\rho_d\frac{\partial f(\phi)}{\partial\phi}} \;\&\; D_T = \frac{\mu(\phi)\,\phi\frac{\partial P_{sat}(T)}{\partial T}}{\rho_d} \qquad (3)$$

The above equations may be derived by introducing the sorption isotherm function (f) and applying the chain rule to Fick's steady-state diffusion equation with the gradient of the water-vapor pressure used as the driving-force potential.

In the capillary regime, a liquid diffusivity ($D_\gamma$) is used in Equation (1). It is calculated using procedures given in Burch and Thomas (1991). The diffusivity for the temperature gradient ($D_T$) is calculated using the second relation of Equation (3).

The model also has a provision for including non-storage layers (e.g., an air space, glass-fiber insulation, a vapor retarder, etc.) that may be sandwiched between two storage layers. In a non-storage layer, the storage of heat and moisture is neglected, and the transfer rate of heat and moisture is assumed to be steady. A non-storage layer may be convectively coupled directly to indoor or outdoor air. A more complete description of the theory is given in Burch and Thomas (1991).

### Solution Procedure

Equations (1-2) are recast into finite-difference equations using a uniform nodal spacing within each layer and are solved using an implicit solution technique with coupling between the two conservation equations. MOIST is written in FORTRAN 77 using a tridiagonal-matrix solution algorithm. At each time step, the calculation proceeds by first solving for the temperature distribution, after which a set of moisture contents are calculated.

In the analysis, a time step of one hour was used. For the current-practice wall construction given in Figure 1, the following number of finite-difference nodes were used in the analysis: 2 in the gypsum board, 3 in fiberboard sheathing, and 3 in the aluminum siding. A similar nodal structure was used for the alternative wall designs. The insulation was treated as a non-storage layer. When MOIST was run on a computer with a 90 Mhz Pentium processor, approximately 5 minutes of computer time was required to simulate one year of real time.

NIST recently conducted a series of laboratory experiments to verify the accuracy of MOIST (Zarr, Burch, and Fanney 1995). As part of these experiments, twelve 1.0 m (3.3 ft.) by 1.1 m (3.6 ft.) wall specimens were installed in the NIST calibrated hot box. Each of the wall specimens was instrumented to measure the moisture content of the construction layers. The moisture and heat transfer properties were independently measured. The exterior surfaces of the test walls were subsequently exposed to steady and time-dependent winter outdoor conditions. With the exception of one of the wall specimens, MOIST predicted the moisture content within 1% moisture content of corresponding measured values.

## PARAMETERS NEEDED FOR ANALYSIS

The following diffusion properties and boundary conditions were used as input to model MOIST.

### Diffusion Properties

A plot of the equilibrium moisture content versus the relative humidity (called a sorption isotherm) for the construction materials is given in Figure 2a. These curves are mean data between adsorption and desorption processes. The data are based on measurements by Richards, et al. (1992).

A plot of the permeance of the construction materials is given in Figure 2b. The data for fiberboard sheathing, exterior-grade plywood, gypsum board, and kraft paper vapor retarder are based on measurements by Burch, et al. (1992). The data for oriented strand board is based on measurements conducted at NIST and presented in Burch (1992).

The storage of moisture in several of the construction materials was considered to be small and unimportant and was therefore neglected. The water-vapor permeance of these materials are summarized in Table 1.

### Boundary Conditions

In the computer simulations, the indoor air temperature and relative humidity were assumed to be 23°C (74°F) and 50%, respectively. The performance in hot and humid climates of the two alternative wall designs was also evaluated with a more severe indoor temperature of (21°C) 70°F and relative humidity of 50%.

Hourly ASHRAE Weather Year for Energy Calculations (WYEC) for a cold climate (Madison, WI), a hot and humid climate (Miami, FL), and a mixed climate (Little Rock, AR) were used in the analysis (Crow 1981).

The temperature and moisture content of the construction layers was initially assumed to be uniform. Six months of weather data were used to initialize the reported 1-year simulation results in order to reduce the effects of assumed initial moisture content and temperature for the layers of the construction.

## PERFORMANCE OF CURRENT PRACTICE WALL

### Wall Description

The construction of the current practice wall is given in Figure 1. From inside to outside, this wall is comprised of latex paint, 7.9 mm (0.31 in.) gypsum board, 89 mm (3.5 in.) glass-fiber insulation, 12.7 mm (0.5 in.) fiberboard sheathing, and aluminum siding. We assumed that the aluminum siding offers little resistance to water vapor flow because ventilation air can freely enter between the siding and the sheathing. The combined permeance of the fiberboard sheathing and the aluminum siding is considerably greater than the 290 $ng/s{\cdot}m^2{\cdot}Pa$ (5 perm) required by practice 2 of the HUD Standards. Therefore, the HUD Standards do not require this wall to have an interior vapor retarder. The interior surface of this wall was assumed to be air tight and moisture transfer by air movement was neglected.

### Results and Discussion

Performance in a cold climate. We first used MOIST to predict the performance of the current practice wall without an interior vapor retarder exposed to the climate of Madison, WI. The surface relative humidity at opposite sides of the wood fiberboard sheathing are plotted versus time of year in Figure 3a. The surface relative humidity is seen to be saturated ($\phi$ = 97%) for a 3-month period, indicating the presence of free liquid water in the pore structure of the fiberboard. These results indicate the practice of providing permeable sheathing and siding may not provide satisfactory moisture performance in a cold climate.

MOIST was next used to predict the performance of the same wall with an interior vapor retarder consisting of vinyl wall paper having a permeance of 29 $ng/s{\cdot}m^2{\cdot}Pa$ (0.5 perm). The results are given in Figure 3b. Here, the surface relative humidity is always significantly below saturation, indicating that the fiberboard sheathing remained dry during the winter. Similar results were obtained with latex paint instead of vinyl wallpaper and a kraft paper vapor retarder installed at the inside surface of the glass-fiber insulation. The above results indicate that the use of an interior vapor retarder provides satisfactory moisture performance in a cold climate. It is worth noting that, in addition to a vapor retarder, it may also be necessary to use an air barrier (to prevent moisture transfer by air movement) in order to achieve satisfactory moisture performance.

Performance in a hot and humid climate. We next used MOIST to investigate the performance of this current practice wall with an interior vapor retarder in a hot and humid climate (Miami, FL). Consistent with the provisions of the HUD Standards, manufactured homes with an interior vapor retarder are sold and distributed to regions with a hot and humid climate.

We first considered the use of vinyl wallpaper as an interior vapor retarder. The surface relative humidity at opposite sides of the gypsum board are plotted versus time of year in Figure 4a. Here it is seen that the surface relative humidity of the gypsum board substantially rises above 80% during a 5-month summer period, indicating a potential for mold and mildew growth. Monthly-mean surface relative humidities above 80% are widely believed to be conducive to mold and mildew growth (International Energy Agency 1990).

An explanation of this result is that the gypsum board is cooled by the air conditioning and a temperature and vapor pressure gradient is established that causes moisture to diffuse inwardly into the construction from the hot and humid outdoor environment. The vinyl wallpaper offers a very large resistance to water-vapor transfer, thereby causing moisture to accumulate behind the vinyl wallpaper. This problem gets progressively worse with lower indoor thermostat settings.

We next considered the case of the same wall with a kraft paper vapor retarder at the inside surface of the glass-fiber insulation and the vinyl wallpaper replaced with permeable latex paint. The surface relative humidity at opposite surfaces of the vapor retarder are plotted versus time of year in Figure 4b. Here it is seen that the surface relative humidity at the outside surface of the vapor retarder rises above the critical 80% level for a 4-month summer period, again providing a conducive environment for the growth of mold and mildew.

To isolate the role of the interior vapor retarder, we compared the performance of the wall with the vinyl wallpaper and the wall with the kraft paper vapor retarder with that of an identical wall without either vinyl or kraft paper, but with an interior latex paint. The results, not presented in full in this paper, show that surface relative humidities at the gypsum board surfaces remain below 80% RH, but are above 70% RH for about a four-month period during mid-summer. The performance of this wall in the Miami climate could be labelled "marginal" but it is clear that the addition of an interior vapor retarder creates much higher relative humidities at its surface, thereby providing an environmental much more conducive to mold and mildew growth.

It is worth mentioning that the application of additional layers of interior latex paint will increase moisture accumulation at interior materials of walls exposed to hot and humid climates and decrease moisture accumulation at exterior materials of walls exposed to cold climates.

## PERFORMANCE OF ALTERNATIVE WALLS

Two walls were identified as having potential for satisfactory moisture performance in a wide variety of climates. The moisture performance of these two walls is investigated for a cold climate (Madison, WI), a hot and humid climate (Miami, FL), and a mixed climate (Little Rock, AR).

### Wall Description

The first alternative wall is shown in Figure 5a. The interior and exterior claddings of this wall consist of 12.7 mm (0.5 in.) exterior-grade plywood, sandwiching 89 mm (3.5 in.) glass-fiber insulation. The interior of this wall is finished with 7.9 mm (0.31 in.) gypsum board. Latex paint is applied to the interior and exterior surfaces. We call this wall a variable-permeance-claddings wall. The term "variable permeance" comes about from the moisture behavior of plywood (see Figure 2b). When plywood is exposed to ambient relative humidities below 50%, it performs as a vapor retarder. On the other hand, when plywood absorbs moisture and approaches saturation, it becomes very permeable.

The second wall is called a "sandwich panel wall with low-permeability insulation" (see Figure 5b). This wall is comprised of interior and exterior claddings of 11.9 mm (0.47 in.) oriented strand board that is glued to 89 mm (3.5 in.) expanded polystyrene insulation (molded beads). The interior of this wall is finished with 7.9 mm (0.31 in.) gypsum board, and the exterior is finished with lapped vinyl siding. Latex paint is applied to the interior surface.

### Results and Discussion

Variable-Permeance-Claddings Wall. In this section, we first use MOIST to investigate the moisture performance of the variable-permeance-claddings wall exposed to the weather of Madison, WI. The relative humidity at the construction layer surfaces are plotted versus time of year in Figure 6. The peak surface relative humidity is seen to occur at the inside surface of exterior plywood layer during the middle of the winter and is seen to be below saturation (97%). This indicates that free liquid water is unlikely to be present in the pore structure of the construction materials. However, the surface relative humidity does at times exceed the critical 80% level, but concurrent temperatures are too low for mold and mildew growth. This construction is, therefore, likely to have satisfactory moisture performance during the cold winter climate, especially since this evaluation was conducted with relatively high indoor humidity conditions.

During the winter, the interior plywood layer functions as an interior vapor retarder and significantly reduces the ingress of moisture into the construction from the indoor environment. From curves 2 and 3 of Figure 6, most of the interior plywood is exposed to relative humidities less than 50%. From curve 2 of Figure 2, the permeance of plywood is seen to be near 57.45 $ng/s{\cdot}m^2{\cdot}Pa$ (1 perm). As the moisture content of the exterior plywood rises during the winter, its permeance increases, thereby permitting accumulated moisture to be transferred through the plywood to the outdoor environment.

We next used MOIST to investigate the moisture performance of the variable-permeance-claddings wall exposed to the weather of Miami, FL. Figure 7a shows the results when the indoor air is maintained at 24°C (75°F) and 50% RH. All the surface relative humidities remained below the critical 80% RH level throughout the year, and we therefore would not expect any mold and mildew growth in this wall.

During the early summer, moisture begins to accumulate in the interior plywood, increasing its permeance beyond that of the exterior plywood. As a result, the interior plywood is able to transfer moisture out of the wall cavity to the building interior faster than the exterior plywood is able to transfer moisture from the outdoor environment into the cavity. The relative humidity therefore remains below the critical level inside the wall.

We conducted the above analysis using an indoor ambient temperature of 24°C (75°C). Burch (1993) previously showed that significantly higher moisture accumulates at interior surfaces as the indoor temperature is decreased below the outdoor dew-point temperature. Therefore, we repeated the simulation given in Figure 7a with an indoor temperature of 21°C (70°F). The results are shown in Figure 7b and indicate that the lower indoor temperature has very little effect on the moisture conditions in this particular wall.

We next used MOIST to investigate the performance of this wall in a mixed climate using the weather data of Little Rock, AR. The results are given in Figure 8. All surface relative humidities are again less than saturation (97%) during winter and less than the critical 80% level during summer.

These results further demonstrate that the variable-permeance concept is suitable for a wide variety of indoor and outdoor conditions.

<u>Sandwich Panel Wall with Low-Permeability Insulation</u>. We conducted a similar analysis to investigate the moisture performance of the sandwich panel wall.

The results for the cold winter climate (Madison, WI) are given in Figure 9. The surface relative humidity at the construction layers are seen to be below saturation (97%), except during brief periods of intermittent wetting at the inside surface of the exterior glue layer. Periodic surface wetting is considered unlikely to lead to decay or cause dimensional instability of the oriented strand board. However, the effect of the accumulated moisture on the bond between the insulation and the board is not known and may warrant investigation.

The results for the hot and humid climate (Miami, FL) are shown in Figures 10a and 10b. Figure 10a shows the moisture conditions when the indoor temperature is held at 24°C (75°F) and Figure 10b shows the results for a more severe 21°C (70°F) indoor temperature. Both figures clearly show that relative humidities remain well below the critical 80% level at all times, and thus no problems with mold and mildew growth are likely to occur in this wall in this climate.

The results for the mixed climate (Little Rock, AR) are given in Figure 11. All surface relative humidities are seen to be below saturation (97%) during winter and the critical 80% level during summer.

We attribute the satisfactory moisture performance of this wall to the very low permeance of both the exterior and interior claddings which significantly limits the ingress of moisture from both the indoor or outdoor environments. The claddings consist of oriented strand board with an attached glue layer which has a combined permeance less than 57 $ng/s{\cdot}m^2{\cdot}Pa$ (1 perm). In addition, the relatively low permeance of the polystyrene further serves to reduce the amount of water vapor reaching the cold side of the wall cavity.

It is worth mentioning that both of the alternative walls probably would be permitted under the current rules of the HUD Standards, since it could be argued that both constructions contain an interior vapor retarder as measured by the ASTM E96 dry cup method (ASTM 1993).

It is also worth mentioning that structural insulated panels (i.e., expanded polystyrene sandwiched between the two oriented strand boards) are currently marketed for sandwich panel walls. Similar structural insulated panels with plywood faces are also currently marketed. A complete package of pre-cut panels are sent to the job site for quick and easy erection by the builder. The authors would like to point out that the use of structural insulated panels may not be economically competitive with standard construction. However, the moisture principles contributing to their satisfactory moisture performance are applicable to walls constructed with more cost effective materials. If any significant deviations are made from the materials used in the examples in this paper, the performance of the wall should be first evaluated using a computer model like MOIST.

## SUMMARY AND CONCLUSIONS

A detailed computer analysis was conducted to investigate the moisture performance of a current-practice wall and two alternative walls in a cold climate (Madison, WI), a hot and humid climate (Miami, FL), and a mixed climate (Little Rock, AR). The analysis revealed that both alternative walls should have satisfactory moisture performance in the three climates considered. That is, the surface relative humidity at the construction layers was shown to be less than saturation (97%) during winter periods and less than a critical 80% level (believed to coincide with mold and mildew growth) during summer periods. Both alternative walls should be permitted under the current rules of the HUD Standards, since both contain an interior vapor retarder. It should be pointed out that we only evaluated the walls' ability to remain dry under a variety of conditions; we did not analyze the walls' ability to dry after accidental wetting or if built with wet materials.

A current-practice manufactured housing wall with an interior vapor retarder was shown to provide satisfactory performance in cold climates, but poor performance in a hot and humid climate. The use of an interior vapor retarder in the wall of an air conditioned building exposed to a hot and humid climate can cause high relative humidity at its outside surface, thereby providing a conducive environment for mold and mildew growth.

A strong need exists to modify the rules of the current HUD Standards for controlling moisture in the walls of manufactured housing, particularly with regard to hot and humid climates.

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## NOMENCLATURE

| Symbol | Units | Definition |
|---|---|---|
| C | J/kg·°C | Specific heat |
| $D_\gamma$ | m²/s | Diffusivity for moisture gradient |
| $D_T$ | m²/°C·s | Diffusivity for temperature gradient |
| f | | Sorption isotherm function |
| k | W/m·°C | Thermal conductivity of porous material |
| P | Pa | Water-vapor pressure |
| t | s | Time |
| T | °C | Temperature |
| y | m | Distance from inside surface of wall |
| $\gamma$ | kg/kg | Moisture content on dry basis |
| $\mu$ | kg/s·m·Pa | Water-vapor permeability |
| $\rho$ | kg/m³ | Density |
| $\phi$ | | Relative humidity |

Subscripts Refer to:

d = Dry property
sat = Saturated state
T = Temperature gradient
w = Moist or water property
$\gamma$ = Moisture content gradient

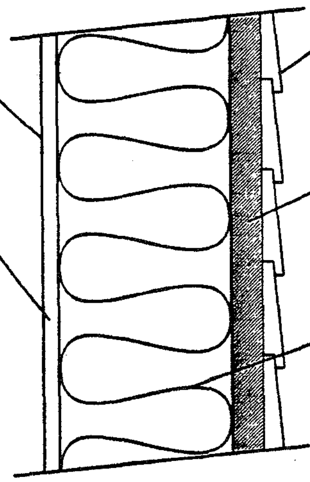
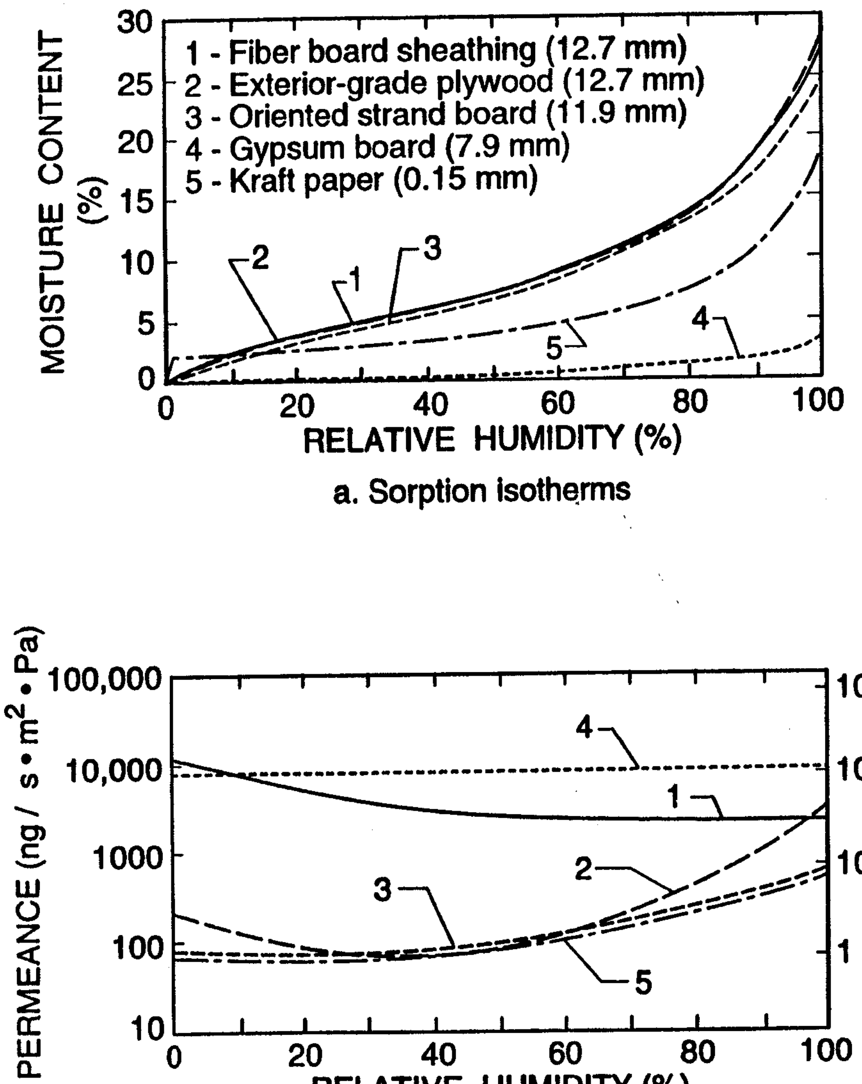



Fig. 1 Current practice wall construction

**Table 1**
**Permeance of Non-Storage Layers**

| Material | Permeance $perm_{SI}$ | Permeance $perm_E$ | Source |
|---|---|---|---|
| Latex Paint | 570 | 10 | ASHRAE (1993) |
| 89 mm (3.5 in.) Glass-Fiber Insulation | 1900 | 33.1 | ASHRAE (1993) |
| 89 mm (3.5 in.) Expanded Polystyrene (Molded Beads) | 63 | 1.1 | ASHRAE (1993) |
| 6-mil Glue | 57 | 1 | Estimate |
| Vinyl Wallpaper | 29 | 0.5 | Burch, et al. (1992) |

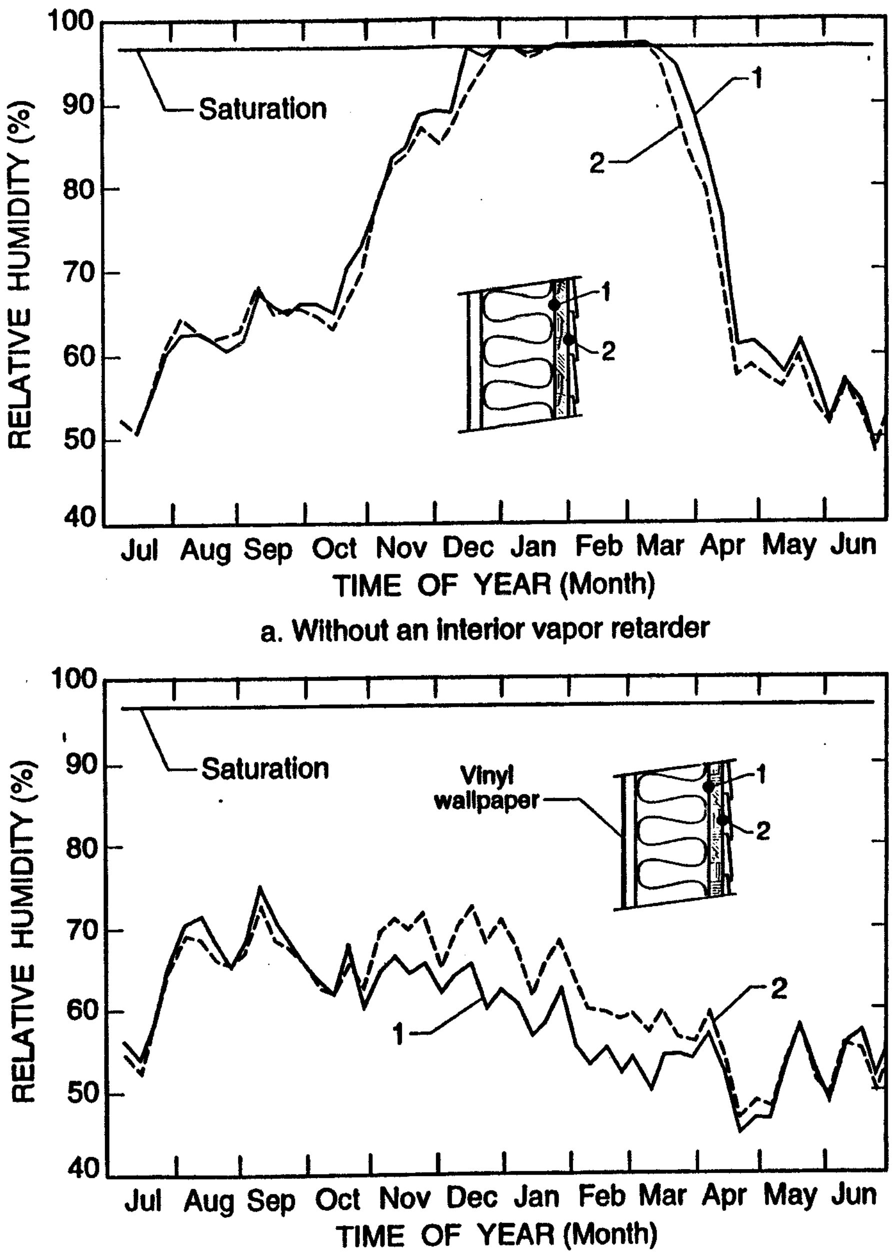
Note: $perm_{SI}$ = ng/(s·m²·Pa) and $perm_E$ = grain/(h·ft²·inHg).




a. Sorption isotherms

b. Permeances

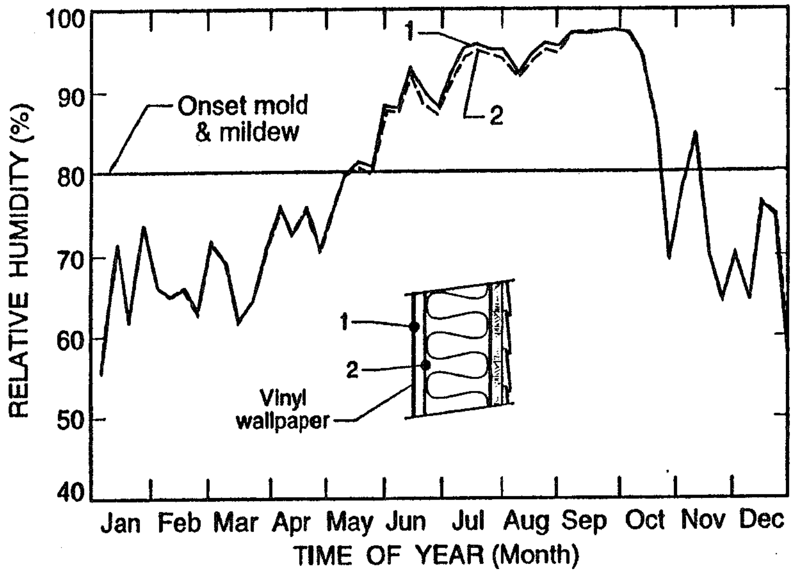
Fig. 2. Diffusion properties of hygroscopic materials



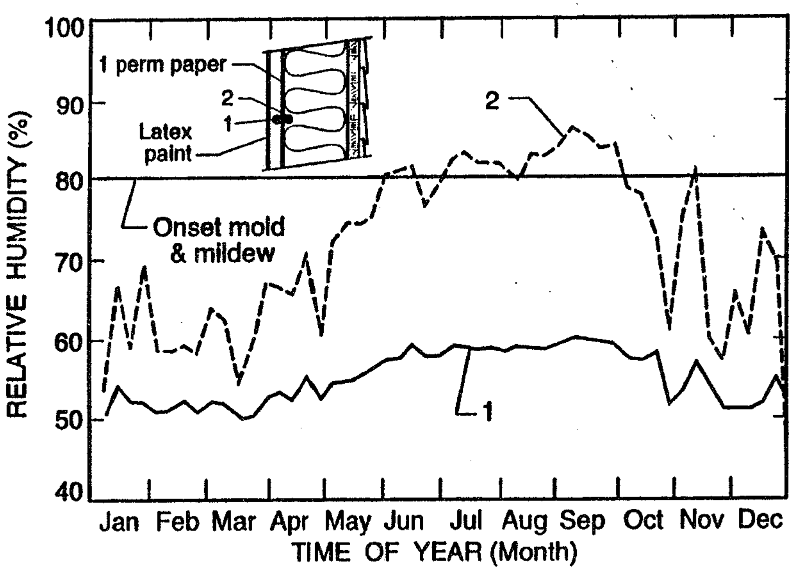

a. Without an interior vapor retarder

b. With an interior vapor retarder

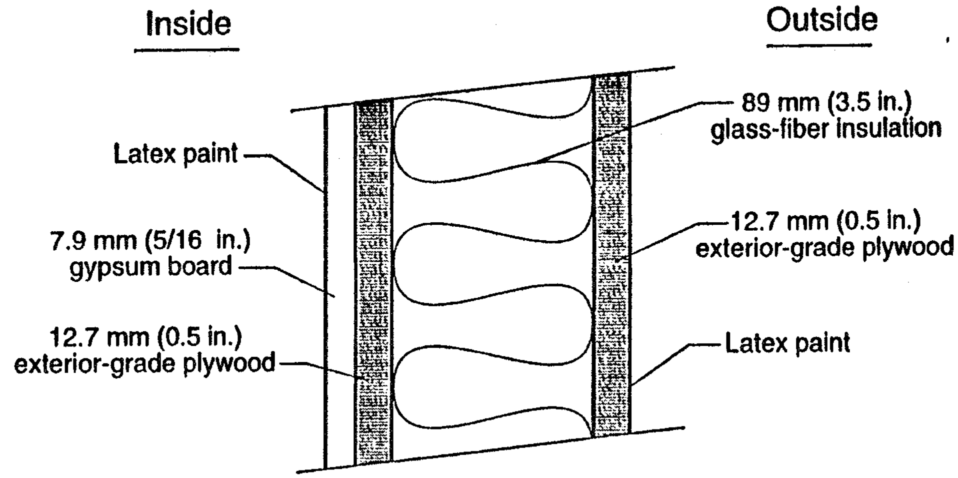
Fig. 3. Surface relative humidity of layers plotted versus time of year for current practice wall exposed to Madison, WI weather data.



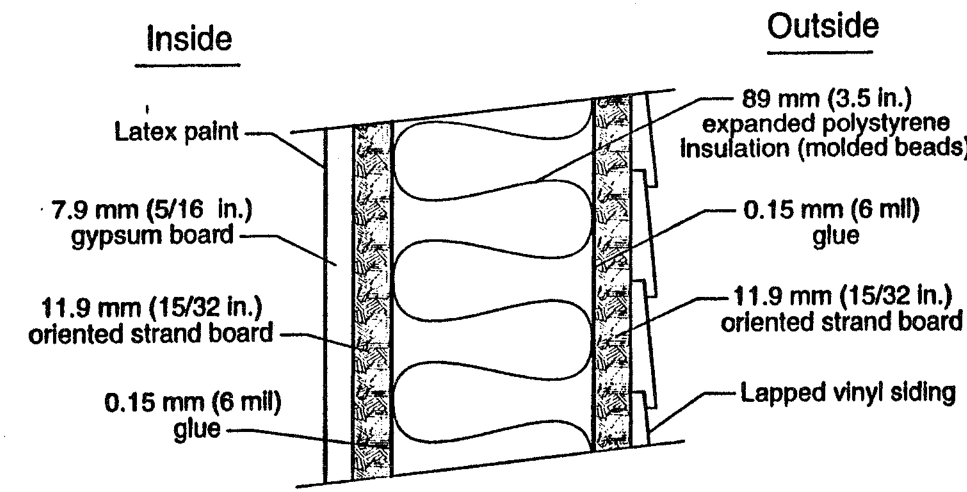

a. Interior vapor retarder is vinyl wallpaper




b. Interior vapor retarder is paper on inside surface of insulation




a. Variable - Permeance - Claddings Wall




b. Sandwich panel wall with low-permeability insulation

Fig. 4. Surface relative humidity of layers plotted versus time of year for current practice wall (with an interior vapor retarder) exposed to Miami, FL weather data.

Fig. 5. Innovative wall constructions

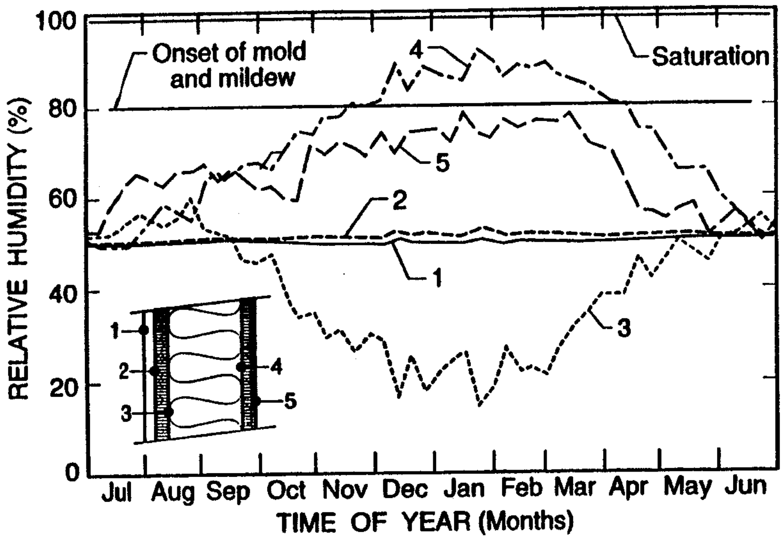



Fig. 6. Surface relative humidity of layers plotted versus time of year for variable-permeance-claddings wall exposed to Madison, WI weather.

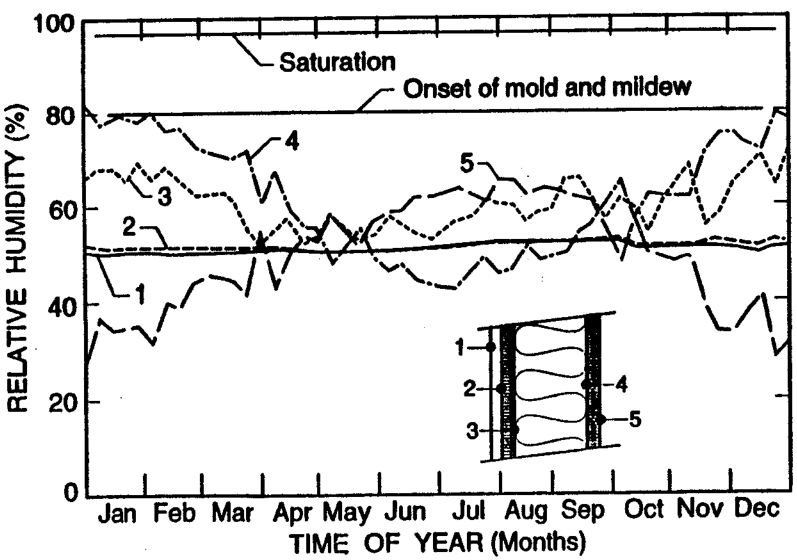
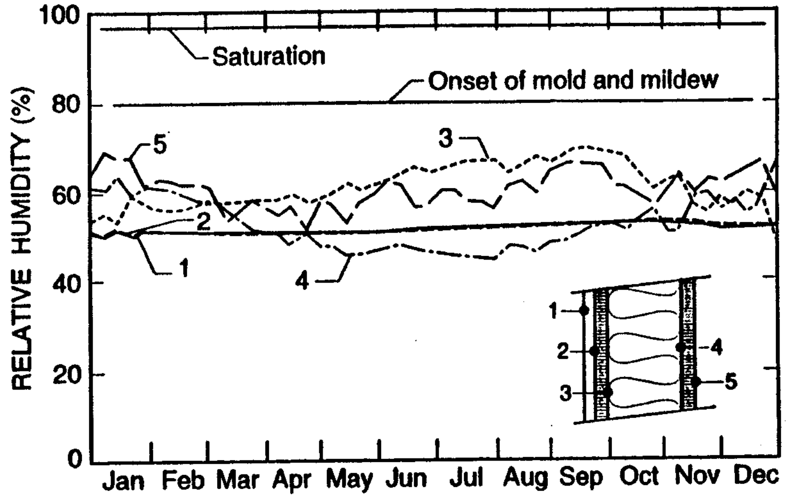
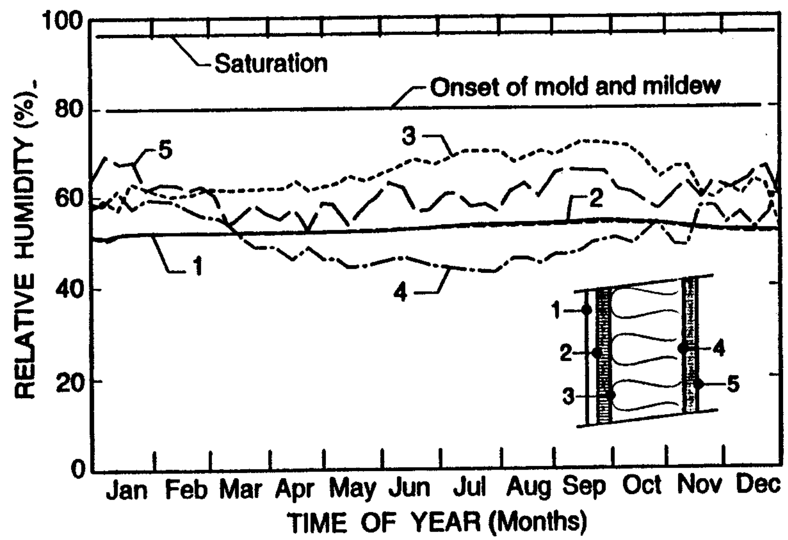



Fig. 8. Surface relative humidity of layers plotted versus time of year for variable-permeance-claddings wall exposed to Little Rock, AR weather.




a. Indoor temperature of 24°C (75°F)




b. Indoor temperature of 21°C (70°F)

Fig. 7. Surface relative humidity of layers plotted versus time of year for variable-permeance-claddings wall exposed to Miami, FL weather.

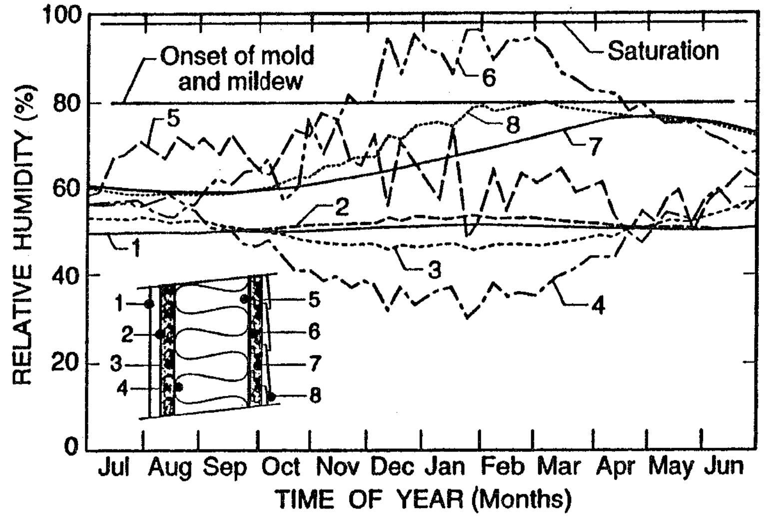



Fig. 9. Surface relative humidity of layers plotted versus time of year for sandwich-panel wall exposed to Madison, WI weather.

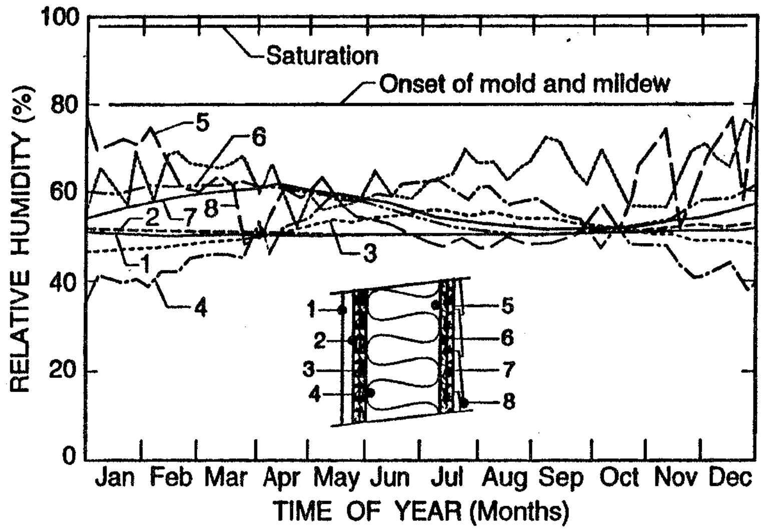
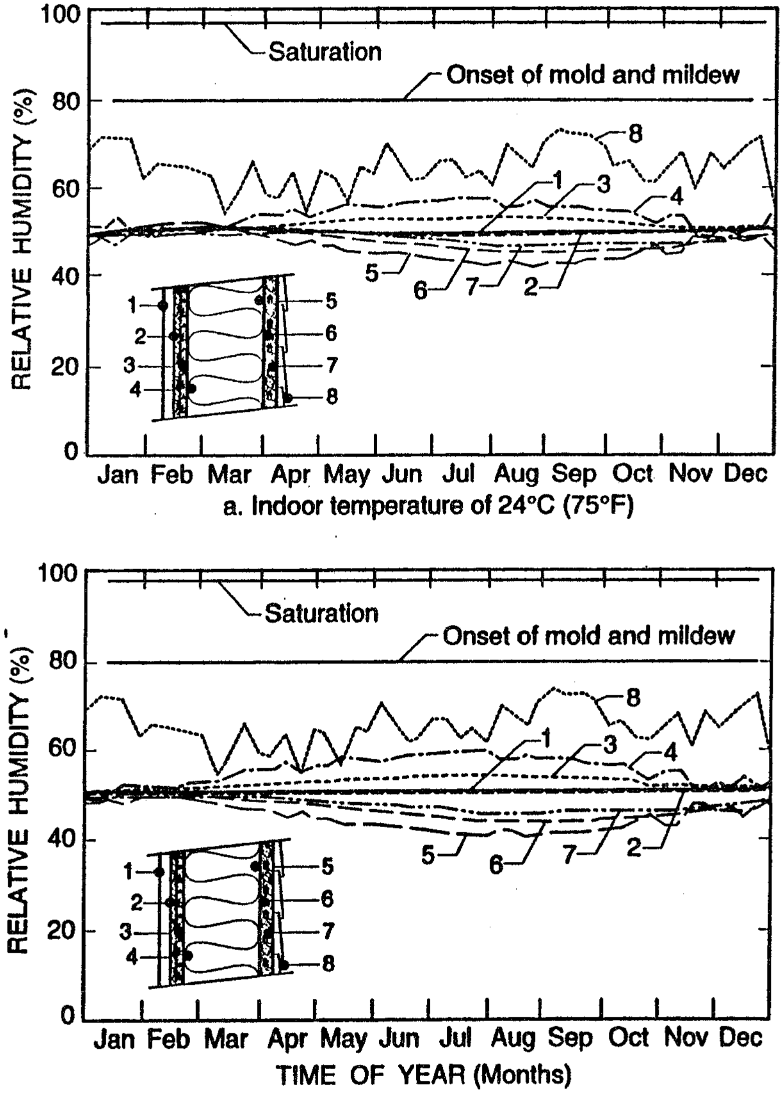



Fig. 11. Surface relative humidity of layers plotted versus time of year for innovative sandwich-panel wall exposed to Little Rock, AR weather.




a. Indoor temperature of 24°C (75°F)

b. Indoor temperature of 21°C (70°F)

Fig. 10. Surface relative humidity of layers plotted versus time of year for innovative sandwich-panel wall exposed to Miami, FL weather.